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(54) **Magnetic resonance apparatus comprising integrated gradient r.f. coils.**

(57) In a magnetic resonance apparatus a gradient coil system and an r.f. coil are combined so as to form a magnetically, electrically and structurally integrated coil system. Thus, a substantial saving is realized as regards the activation energy required for generating gradient fields as well as for generating r.f. fields and notably r.f. stray-fields are also reduced.

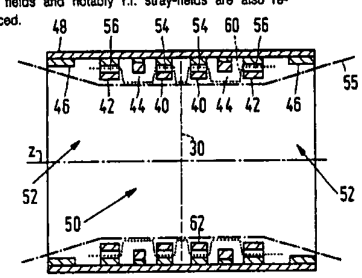

FIG.2a

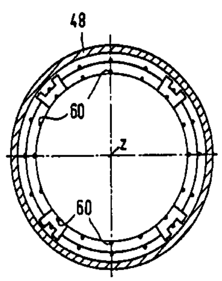

FIG.2b

Magnetic resonance apparatus comprising integrated gradient r.f. coils.

The invention relates to a magnetic resonance apparatus, comprising a magnet system for generating a steady magnetic field, a magnet system for generating mutually perpendicular gradient fields, and an r.f. coil for generating a spatially uniform r.f. magnetic field.

A magnetic resonance apparatus of this kind is known from an article in Computertomography 1, 1981, pages 2-10.

In an apparatus of this kind use is preferably made of a superconducting magnet system for generating the steady magnetic field, notably for apparatus involving a comparatively strong magnetic field, for example stronger than 0.5 T. The problem of high energy consumption for generating the steady field is thus circumvented. Because of its comparatively short switching times, it is difficult to construct a gradient coil system from superconducting coils. Therefore, the gradient coil system in known apparatus is one of the components having the highest energy consumption. The energy stored in such a coil system increases as the fifth power of the coil dimension. The smaller the coil is, the more efficient it will operate. A large amount of stored energy is unattractive not only because of the energy costs, but notably also because it impedes the realization of short switching times and an increasing number of disturbing phenomena occurs as the amount of energy required increases.

Known coil systems, for generating a uniform r.f. transmitter field in a comparatively large measuring space also require a comparatively large amount of energy. Moreover, the homogeneity of an r.f. field to be generated is affected by the presence of the gradient coils; a customary r.f. shield necessitates the use of complex and expensive power supply equipment.

It is the object of the invention to provide a magnetic resonance apparatus in which the energy required for the gradient coil system and for the r.f. coil system is reduced and in which the homogeneity of notably the r.f. field in a measuring space is at least equivalent to the homogeneity in known apparatus.

To achieve this, a magnetic resonance apparatus of the kind set forth in accordance with the invention is characterized in that the gradient coil system and the r.f. coil are combined so as to form an magnetically/structurally integrated gradient r.f. coil system.

Because current conductors of gradient coils can be positioned substantially in one and the same cylinder generated surface, a coil system can be realized which has a substantially smaller diameter and hence a substantially lower energy consumption, and adverse effects on the r.f. field by the r.f. shield and the gradient coils can be reduced.

To this end, in a preferred embodiment current conductors of gradient coils serve as a shield for an r.f. coil system, so that the field homogeneity of the r.f. field is improved as well as stray-fields of the r.f. coils are reduced.

In a further preferred embodiment, current conductors of r.f. coils are integrated in structural members of the gradient coil system, the current conductors not being situated at the same distance from an axis of rotation in all locations, if desired.

In another preferred embodiment, arc conductors of gradient coils which are situated further outwards are integrated with r.f. coils so that a larger diameter can be achieved for the coil system, so that the accessibility for a patient to be examined is improved. On the other hand, a central portion of the coil system may thus have a smaller diameter, thus reducing the energy required.

Some preferred embodiments in accordance with the invention will be described in detail hereinafter with reference to the drawing. Therein:

Figure 1 shows a magnetic resonance apparatus in accordance with the invention;

Figure 2 diagrammatically shows an axial and a radial cross-section of an integrated gradient r.f. coil system.

A magnetic resonance apparatus as shown in Figure 1 comprises a magnet system 2 for generating a steady, uniform magnetic field, an integrated magnet system 4 for generating magnetic gradient fields and r.f. magnetic alternating fields, and power supply sources 6 and 8 for the magnet system 2 and the magnet system 4, respectively. A magnet coil 10 of the integrated magnet system 4 is connected to an r.f. source 12. For the detection of magnetic resonance signals generated by the r.f. transmitter field in an object to be examined use can be made of, for example a surface coil 13. For reading, the coil 13 is connected to a signal amplifier 14. The signal amplifier 14 is connected to a phase-sensitive rectifier 16 which is connected to a central control device 18. The central control device 18 also controls a modulator 20 for the r.f. source 12, the supply source 8 for the gradient coils, and a monitor 22 for display. An r.f. oscillator 24 controls the modulator 20 as well as the phase-sensitive rectifier 16 which processes the measuring signals. For cooling, if necessary, there is provided a cooling device 26 comprising cooling ducts 27. A cooling device of this kind can be con-

structed as a water cooling system for resistance coils or as a dewar system for superconducting coils. The transmitter coil 10 which is arranged within the magnet systems 2 and 4 encloses a measuring space 28 which offers adequate room for accommodating patients in the case of an apparatus for medical diagnostic measurements. Thus, a steady magnetic field, gradient fields for position selection of slices to be imaged, and a spatially uniform r.f. alternating field can be generated in the measuring space 28.

A gradient magnet system 4 is symmetrically arranged with respect to a radial symmetry plane 30 in a customary manner, which symmetry plane thus also subdivides the measuring space symmetrically into two halves and is directed through a point Z = 0 transversely of a Z-axis. The steady magnetic field generated by the steady magnet system is directed along the Z-axis in the present embodiment. A gradient magnet system in a magnetic resonance apparatus customarily comprises, for each of the coordinate directions, a coil system which can be activated in order to generate gradient fields in each of the directions, enabling point-wise imaging of an object.

Figure 2a is an axial sectional view of an integrated gradient r.f. coil system 4 and Figure 2b is a radial sectional view thereof. Symmetrically with respect to the radial symmetry plane 30 there are arranged, for example combined X- and Y-gradient coil arc conductor stacks 40 and 42, two Z-gradient coil arc conductors 44 and current return arc conductors 46. For the invention it is irrelevant how many of such arc conductors stacks are included in the gradient coil system and how they are distributed and integrated. For example, a Z-gradient coil arc conductor stack can also be oriented in the Z-plane and, if desired, ZZ-gradient arc conductors which customarily form substantially complete rings can be integrated with X- and Y-gradient arc conductors which are azimuthally shifted through 90° with respect to one another and which extend through azimuthal arc angles of, for example from approximately 90° to approximately 180°. A cylinder 48, closed or not, provides axial interconnection of coil components of the gradient coil system. In the present embodiment, the cylinder 48 deliberately has a diameter which is larger than the outer diameter of, for example the arc conductor stacks 40 and 42 and the current return arc conductor stack 46 is mounted directly against the cylinder 48. As a result, the system can have a cylindrical shape with a central portion 50 having a diameter of, for example approximately 60 cm, terminating in conical ends 52 having a diameter which increases to, for example approximately 75 as diagrammatically denoted by a stroke line 55, so that the described advantages are obtained.

Intermediate pieces 54 and 58 for notably the X-Y coil arc conductor stacks 40 and 42 are made of an electrically insulating, non-magnetic material and preferably form closed rings. Axially directed conductors 60 of of an r.f. coil, for example in the form of a bird-cage coil as disclosed in EP 213665, are included in the gradient coil system, for example by making these conductors extend through the intermediate pieces of the arc conductor stacks as shown in Figure 2a. The conductors 60 may also be arranged along or in the cylinder 48 or may be mounted, for example against an inner side 62 of the arc conductor stacks. Such a mounting results in a cylindrical coil system which comprises the gradient coils as well as an r.f. transmitter coil and which can be mounted in a magnetic resonance apparatus as one unit. Measured radially, a substantial saving in space is thus obtained, so that notably the energy required for the gradient coil system is substantially reduced. The r.f. field can be modulated in a positive sense by way of adapted positioning of arc conductors or turns of the gradient coil system. As a result, a higher homogeneity can be obtained for the r.f. field and axial propagation of the r.f. field can be strongly reduced, so that fewer stray-fields occur and a lower power supply energy suffices for the r.f. coil system. Due to the rotationally symmetrical construction around at least two mutually perpendicular axial planes, the r.f. coil can operate in the quadrature mode, without any geometrical modification of the coil system being required. Return arc conductors can be positioned and operated so that they exert a compensating effect for r.f. stray-fields. Amplification and power supply equipment can be substantially reduced by the invention, both as regards power and hence complexity and costs.

Claims

1. A magnetic resonance apparatus, comprising a magnet system for generating a steady magnetic field, a magnet system for generating mutually perpendicular gradient fields, and an r.f. coil for generating a spatially uniform r.f. magnetic field, characterized in that the gradient coil system and the r.f. coil are combined so as to form a magnetically/structurally integrated gradient r.f. coil system.

2. A magnetic resonance apparatus as claimed in Claim 1, characterized in that current conductors of the gradient coil system and current conductors of the r.f. coil are situated in substantially the same cylinder generated surface.

3. A magnetic resonance apparatus as claimed in Claim 1 or 2, characterized in that current conductors of a gradient coil system act as shielding members for an r.f. coil.

4. A magnetic resonance apparatus as claimed in Claim 3, characterized in that the location of the current conductors of the gradient coil system and current conductors of the r.f. coil with respect to one another is adapted so as to obtain optimun spatial homogeneity of an r.f. transmitter field to be generated in a measuring space.

5. A magnetic resonance apparatus as claimed in Claim 3 or 4, characterized in that, viewed axially, current conductors of a gradient coil system which are situated further outwards are located so as to obtain optimum shielding of an r.f. stray-field at that area.

6. A magnetic resonance apparatus as claimed in any one of the preceding Claims, characterized in that current conductors of an r.f. coil are accommodated in recesses in structural members of a gradient coil system.

7. A magnetic resonance apparatus as claimed in any one of the preceding Claims, characterized in that, viewed axially, arc conductors of the coil system which are situated further outwards have a diameter which is larger than that of more centrally situated arc conductors.

8. A magnetic resonance apparatus as claimed in any one of the preceding Claims, characterized in that the integrated coil system is symmetrically situated with respect to two mutually perpendicular axial planes in order to enable a quadrature measuring method.

9. An integrated gradient r.f. coil system, evidently intended for a magnetic resonance apparatus as claimed in any one of the preceding Claims.

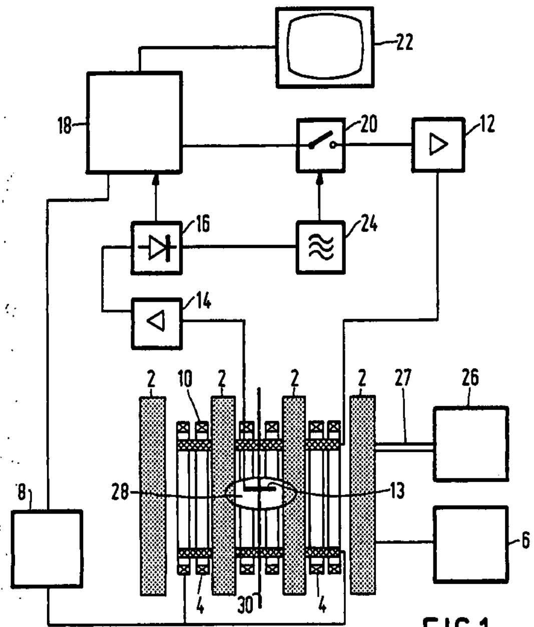

FIG.1

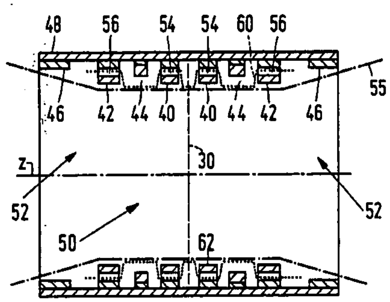

FIG.2a

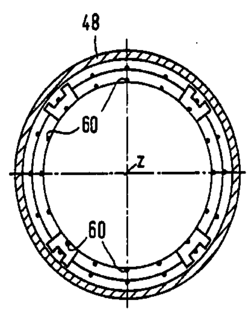

FIG.2b

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EUROPEAN SEARCH REPORT

Application Number

EP 88 20 1729

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
Y	EP-A-0 123 075 (SIEMENS AG) * Page 2, lines 24-29; page 3, lines 24-33; figures 1,2 *	1,2,8,9	G 01 N 24/04 G 01 N 24/06
Y	DE-A-2 854 774 (BATTELLE-INSTITUT E.V.) * Page 4, line 17 - page 6, line 3; page 12, lines 1-17 *	1,9	
A	DE-A-2 951 018 (W.H. BERGMANN) * Page 1, line 1 - page 2, line 20; page 3, lines 17-20 *	1,9	
A	EP-A-0 138 269 (N.V. PHILIPS' GLOEILAMPENFABRIEKEN) * Page 3, lines 7-31; page 4, lines 7-11; figure *	1,2,9	
A,D	COMPUTERTOMOGRAPHIE, vol. 1, no. 1, April 1981, pages 2-10, Georg Thieme Verlag, Stuttgart, DE; A. GANSSEN et al.: "Kernspin-tomographie" * Section 3 *	1	TECHNICAL FIELDS SEARCHED (Int. Cl.4) G 01 N

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	28-11-1988	HORAK G.I.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
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T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
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& : member of the same patent family, corresponding document